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(54) Microwave power combining FET amplifier.

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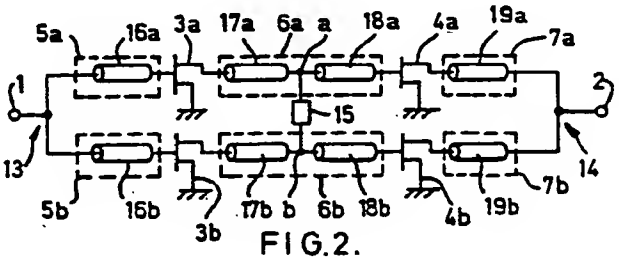

FIG.2.

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MICROWAVE POWER COMBINING FET AMPLIFIER

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a microwave power combining FET amplifier for amplifyinq and combining power of microwave by using a microwave integrated circuit.

Description of the Prior Art

The prior art of this type is disclosed, for example, in T. Takagi, et al, " A 1.5 Watt 28 GHz Band FET Amplifier", 1984 IEEE MTT-S Digest, pp. 227 - 228, and in S.D. Bingham, et al, " A Mniaturized 6.5 - 16 GHz Monolithic Power Amplifier Module", IEEE 1985 Microwave and Millimeter-Wave Monolithic Circuits Symp. Digest, pp. 38 - 41. The former uses two two-stage amplifiers operated in parallel to each other and branch-line couplers for combining power/ splitting, and the latter uses four monolithic two-stage amplifiers operated in parallel to each other and interdigital couplers for combining power/splitting.

Fig.1 is a circuit diagram of a prior art microwave power combining FET amplifier shown, for example, in the above-mentioned 1984 IEEE MTT-S Digest, pp 227 - 228, " A 1.5 Watt 28 GHz Band FET Amplifier". In the Figure, numeral 1 designates an input terminal, 2 an output terminal, 3a and 3b pre-stage FETs, 4a and 4b post-stage FETs, 5a and 5b input matching circuits, 6a and 6b interstage matching circuits, 7a and 7b output matching circuits, 8 a power splitter, and 9 a power combiner. The power splitter 8 and power combiner 9 in Fig.1 use branch-line type couplers or Wilkinson type couplers.

Next, the operation will be described. The microwave power inputted from the input terminal 1 is split by the power splitter 8, and one of the split microwave power is supplied to the power combiner 9 through the input matching circuit 5a, prestage FET 3a, interstage matching circuit 6a, poststage FET 4a, and output matching circuit 7a. The other of the split microwave power is also suplied to the power combiner 9 through the input matching circuit 5b, pre-stage FET 3b, interstage matching circuit 6b, post-stage FET 4b, and output matching circuit 7b. The split two microwave powers are matched respectively by the input matching circuits 5a, 5b, interstag matching circuits 6a, 6b, and output matching circuits 7a, 7b, and at the same time amplified by the FETs 3a, 3b, 4a, and 4b. The two microwave powers supplied to the power combiner 9 are combined, and amplified and combined microwave power is outputted from the output terminal 2.

The power splitter 8 and power combiner 9 have in the inside thereof resistance circuits for isolation, and the resistance circuits for isolation serve to absorb the microwave power which propagates in a propagation mode of odd mode due to microwaves having equal amplitude and oppsite phases caused by non-uniformity of characteristics of individual FETs 3a, 3b, 4a, and 4b. As a result, the amplifier arranged as shown in Fig.1 can be operated stably.

However, as described above, in the prior art amplifier, in order to eliminate the influence of reflection of the microwave due to the non-uniformity of the characteristics of the FETs, it is necessary to provide the resistence circuits for isolation in the inside of the power splitter and the power combiner. For the purpose of providing these resistance circuits for isolation, a branch-line type coupler or a Wilkinson type coupler having such a resistance circuit is reqired separately. As a result, there has been a problem in that the structure of the amplifier is complicated and it is difficult to make the shape small in size.

SUMMARY OF THE INVENTION

The present invention was made to solve the above problem, and it is an object of the invention to provide a microwave power combining FET amplifier without including a power splitting circuit and a power combining circuit which employ a branch-line type coupler or a Wilkinson type coupler, and yet performing equivalent function to these circuits thereby enabling to arrange in a simple structure and in a small size.

The above object is realized by providing a microwave power combining FET amplifier which comprises T-type branch circuits for power splitting and for power combining, a plurality of multistage FETs, interstage matching circuits provided respectively corresponding to the multistage FETs, and a resistance circuit having a predetermined resistance value connected between predetermined opposing positions of the interstage matching circuits.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a circuit diagram of a prior art microwave power combining FET amplifier;

Fig.2 is a circuit diagram showing a first embodiment of the present invention;

Fig.3 is a circuit diagram for explaining the principles of operation of the first embodiment;

Fig.4 is a circuit diagram showing a second embodiment of the invention;

Fig.5 is a circuit diagram showing a third embodiment of the invention; and

Fig.6 is a circuit diagram showing a fourth embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The embodiments of the present invention will be described with reference to the drawings. Fig.2 is a circuit diagram of a microwave power combining FET amplifier according to a first embodiment of the invention. In Fig.2, identical reference numerals are used to refer to corresponding elements in Fig.1, and descriptions thereof are omitted.

In Fig.2, input matching circuits 5a and 5b are constituted by distributed constant transmission lines 16a and 16b respectively, and interstage matching circuits 6a and 6b are respectively constituted by pairs of distributed constant transmission lines 17a, 18a, and 17b, 18b. Furthermore, output matching circuits 7a and 7b are constituted by distributed constant transmission lines 19a and 19b. Between an input terminal 1 and the input matching circuits 5a, 5b, there is provided with a T-type branch circuit 13 for performing power splitting, and a T-type branch circuit 14 is provided between an output terminal 2 and the output matching circuits 7a, 7b for performing power combining. The interstage matching circuits 6a and 6b are provided respectively corresponding to a plurality of FETs (multi-stage FET amplifier) 3a and 4a and a plurality of FETs 3b and 4b, and a resistance circuit 15 having a predetermined resistance value is connected between predetermined positions a and b opposing to each other and respectively in the interstage matching circuits 6a and 6b. In this respect, in a microwave integrated circuit, the distibuted constant transmission lines 16a, 16b, 17a, 17b, 18a, 18b, 19a, and 19b are formed by microstrip lines (line having a single conductor strip disposed in parallel and close to a flat metalic plate). Next, the operation in the first embodiment will be described. The microwave power inputted from the input terminal 1 is split by the T-type branch circuit 13. On of th split microwave power is supplied to the T-type branch circuit 14 through the input matching circuit 5a, pre-stage FET 3a, interstage matching circuit 6a, post-stage FET 4a, and output matching circuit 7a. The other of the split microwave power is supplied to the T-type branch circuit 14 through the input matching circuit 5b, pre-stage FET 3b, interstage matching circuit 6b, post-stage FET 4b, and output matching circuit 7b. Both the microwave powers split by the T-type branch circuit 13 are respectively amplified by the FETs 3a and 4a and the FETs 3b and 4b, and are combined by the T-type branch circuit 14. Accodingly, the amplified and power combined microwave power is outputted.

When there are non-uniformities in the characteristics of the FETs 3a, 3b, 4a, and 4b, the amplitudes and phases of the two microwaves which reach the T-type branch circuit 14 differ from each other. Generally, there are two types of transmission modes of wave, that is, an odd mode in which the amplitudes of two waves are equal and the phases are opposite to each, and an even mode in which the amplitudes and phases of the two waves are equal to each other. Two input microwaves having the same amplitude and phase and propagating in the even propagation mode are combined in the T-type branch circuit 14 and delivered to the output terminal 2. However, two input microwaves having the same amplitude and opposite phases and propagating in the odd propagation mode are reflected at the T-type branch circuit 14. The reflected microwaves propagate in the direction of the T-type branch circuit 13 at the input side, and they are again reflected from the T-type branch circuit 13. Ultimately, multiple reflection is repeated between the T-type branch circuit 13 and the T-type branch circuit 14, and the amplification characteristic is affected adversely. For this reason, in the first embodiment, predetermined positions a and b opposing to each other respectively at th interstage matching circuits 6a and 6b are connected by a resistance circuit 15 to each other to eliminate the influence of the above-m ntioned multiple reflection.

The operation of the arrangement will be described. In order to realize a high output microwave power combining FET amplifier, FETs having a large gate width and a high output level ar used in the post-stage FETs 4a and 4b as compared with the pre-stage FETs 3a and 3b. Generally, since the FETs having a large gate width are apt to exhibit large non-uniformities in the characteristic of the FETs, the non-uniformities in the characteristic tend to become large in the post-stage FETs 4a and 4b as compared with the pre-stage FETs 3a and 3b. Accordingly, here it is supposed that approximately, the pre-stage FETs 3a and 3b have no non-uniformities in the characteristic therebetween, and the post-stage FETs 4a and 4b have non-unifor-

mities in the characteristic therebetween.

Fig.3 is a circuit diagram for explaining the principles of operation when the non-uniformities in the characteristic are present in only the post-stage FETs 4a and 4b. In Fig.3, distributed constant transmission lines 21a and 21b represent the pre-stage FETs 3a and 3b by regarding them approximataely as lines. Furthermore, in Fig.3, θ_1 and θ_3 are respectively electrical angles due to the distributed constant transmission lines 16a, 16b, and the distributed constant transmission lines 17a and 17b, and θ_2 is an electrical angle which is given by the relationship

$$\theta_2 + \fallingdotseq < S_{12} \fallingdotseq < S_{21}$$

among S parameters of the pre-stage FETs 3a and 3b. Here, S_{12} and S_{21} are elements S_{12} , and S_{21} of a so-called

$$S = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}$$

Further, Za and Zb are impedances as viewed the sides of the post-stage FETs 4a and 4b from the points a and b. Numeral 15 designates a resistance circuit having an impedance Z.

Here, the relationshps among the electrical angles θ_1, θ_2, and θ_3, and the relationships among the impedances Za, Zb, and Zc are expressed by

$$\theta_1 + \theta_2 + \theta_3 \fallingdotseq 90° \quad \text{.....(1)}$$

$$Z/2 \fallingdotseq Za^* \fallingdotseq Zb^* \quad \text{.....(2)}$$

Where, Za^* and Zb^* in the formula (2) represent conjugate complexes of Za and Zb.

As will be seen from the relationships in the formulas (1) snf (2), the circuit of Fig.3 can be regarded approximately as being equivalent to the Wilkinson type coupler. Accordingly, the microwave power having the same amplitude and opposite phases reflected due to the non-uniformities in the characteristic of the post-FETs 4a and 4b is consumed by the resistance circuit 15 according to the principles of operation similar to that of the Wilkinson type coupler. In other words, when the microwave power split by the T-type branch circuit 13 reaches the T-type branch circuit 14, it is reflected with the same amplitude and opposite phases towards the input side, and due to this reflection, a potential difference is developed across the resistance circuit 15, and the reflected microwave power is fed to the resistance circuit 15 and consumed therein. In this case, if the non-uniformities in the characteristic are not present in the FETs, even when the resistance circuit 15 is provided, since the voltages applied to both ends of the resistance circuit 15 are equal to each other, no current flows through the resistance circuit 15. Therefore, the resistance circuit 15 does not affect the propagation mode in the even mode which contributes to the amplification characteristic, and the resistance circuit 15 functions as an absorbing circuit for the microwave power propagating in the propagation mode of the odd mode which is a cause of the multiple reflection.

In accordance with the first embodiment described above, it is possible to perform the power splitting or power combining by the T-type branch circuit, and at the same time, it is possible to absorb by the resistance circuit provided at a predetermined position in the interstage metching circuit, the microwave power propagating in the propagation mode of the odd mode due to the non-uniformities in the characteristic of the FETs. By virtue of this, it is possible to prevent the adverse effect on the amplification characteristic and to prevent the unstable operation such as oscillation due to the multiple reflection. Accodingly, in the first embodiment, the power splitter and power combiner using the branch-type or Wilkinson type couples employed in the prior art amplifiers of this kind are not particulary necessary, and the structure can be simplified and the shape can be made small in size.

Fig.4 is a circuit diagram showing a second embodiment of the present invention. In the second embodiment, four multistage FET amplifiers are used, and corresponding constituent parts to that shown in Fig.2 are designated with identical reference numerals. In Fig.4, numerals 3c and 3d designate pre-stage FETs, 4c and 4d post-stage FETs, 5c and 5d input matching circuits, 6c and 6d interstage matching circuits, 7c and 7d output matching circuits, and 13a, 13b, 13c, 14a, 14b, and 14c designate T-type branch cirvuits. The operation in this second embdiment is the same as the first embodiment, and the description thereof is omitted. Furthermore, in this embodiment, three or fiv multistage FET amplifiers or more may be used.

Fig.5 is a curcuit diagram showing a third embodiment. The characteristic features in the third embodiment reside in that each of input matching circuits 5a and 5b is formed by a coil L1 and a capacitor CI, each of interstage matching circuits 6a and 6b is formed by coils L2, L3, and capacitors C2, C3, and each of output matching circuits 7a and 7b is formed by a coil L4 and a capacitor C4. In other words, the input matching circuits 5a and 5b, interstage matching circuits 6a and 6b, and output matching circuits 7a and 7b are formed by concentrated constant circuit elements. In the case of the third embodim nt, the same operation can be performed as in the first embodiment.

Fig.6 is a circuit diagram showinq a fourth

embodiment of the present invention. In Fig.6, the constituent elements corresponding to that in Fig.2 are designated by identical reference numerals and the description thereof is omitted. In the fourth embodiment, two three-stage FET amplifiers are used, and numerals 10a and 10b designate respectively pre-stage FETs, 11a and 11b designate intermediate stage FETs, and 12a and 12b designate post-stage FETs. In the foruth embodiment, also the operation is the same as in the first embodiment. This embodiment may be formed by four stage or more FETs.

Furthermore, the present invention may be applied to a monolithic integrared circuit, and a plurality of FETs, input matching circuits, output matching circuits, interstage metching circuits, T-type branch circuits, and resiatance circuits may be formed on the same semiconductor substrate.

Claims

1. A microwave power combining FET amplifier including a plurality of multistage FET amplifiers (3a,3b,4a,4b) connected in parallel to each other, each of said multistage FET amplifiers having an input matching circuit (5a,5b), an output matching circuit (7a,7b), and an interstage matching circuit (6a,6b), each of said circuits being formed by a microwave integrated circuit, characterised by:

a pair of T-type branch circuits (13,14) respectively for power splitting and for power combining;

a plurality of interstage circuits (6a,6b) provided respectively corresponding to said plurality of multistage FET amplifiers (3a,3b,4a,4b); and

a resistance circuit (15) having a predetermined resistance value connected between predetermined positions (a,b) opposing to each other respectively at said plurality of interstage matching cirucits.

2. A microwave power combining FET amplifier according to claim 1 wherein said plurality of multistage FET amplifiers are formed by four FETs including two pre-stage FETs (3a,3b) connected in parallel to each other and two post-stage FETs (4a,4b) connected in parallel to each other.

3. A microwave power combining FET amplifier according to claim I wherein each of said input matching circuit (5a,5b), said interstage matching circuit (6a,6b), and said output matching circuit (7a,7b) is formed by a concentrated constant circuit element having a coil (L_1,L_2,L_3,L_4) and a capacitor (C_1,C_2,C_3,C_4).

4. A microwave power combining FET amplifier according to claim 1 wherein each of said pluraltiy of multistage FET amplifiers includes a pre-stage FET (10a,10b), an intermediate stage FET (11a,11b), and a post-stage FET (12a,12b), and said plurality of multistage FET amplifiers include two pre-stage FETs, two intermediate stage FETs, and two post-stage FETs respectively in parallel to each other.

5. A microwave power combining FET amplifier according to any one of claims 1 to 4 wherein said microwave power combining FET amplifier is formed by a monolithic intergrated circuit.

6. A microwave power combining FET amplifier substantially as hereinbefore described with reference to Figures 2 and 3 or any one of Figures 4 to 6 of the accompanying drawings.

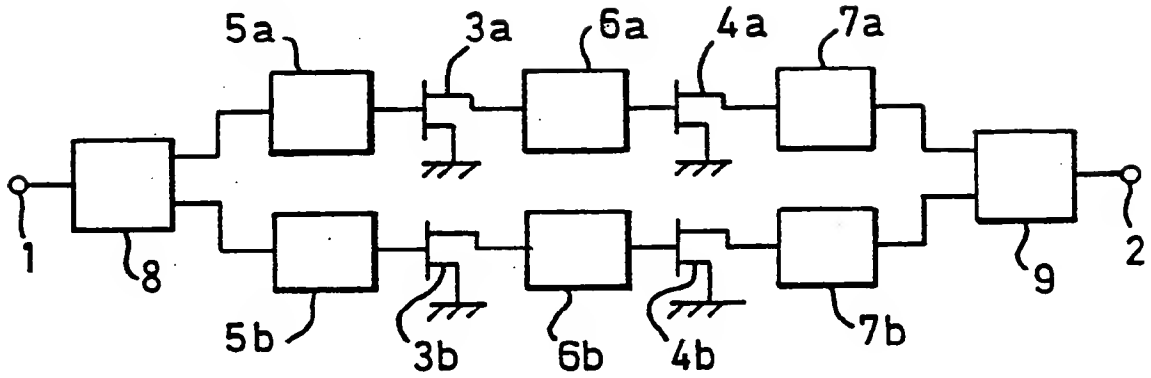

FIG.1.
PRIOR ART

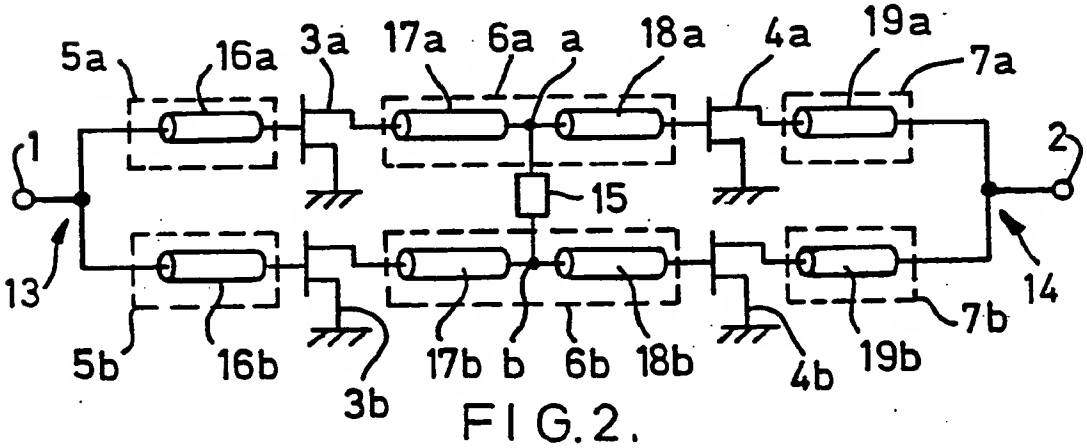

FIG.2.

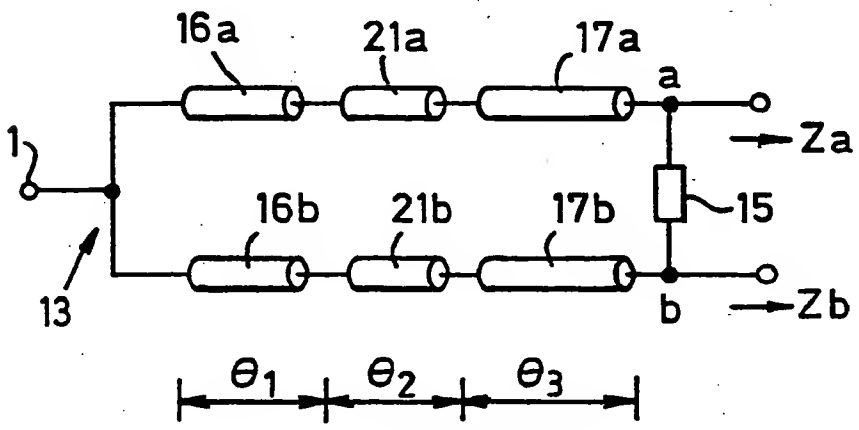

FIG.3.

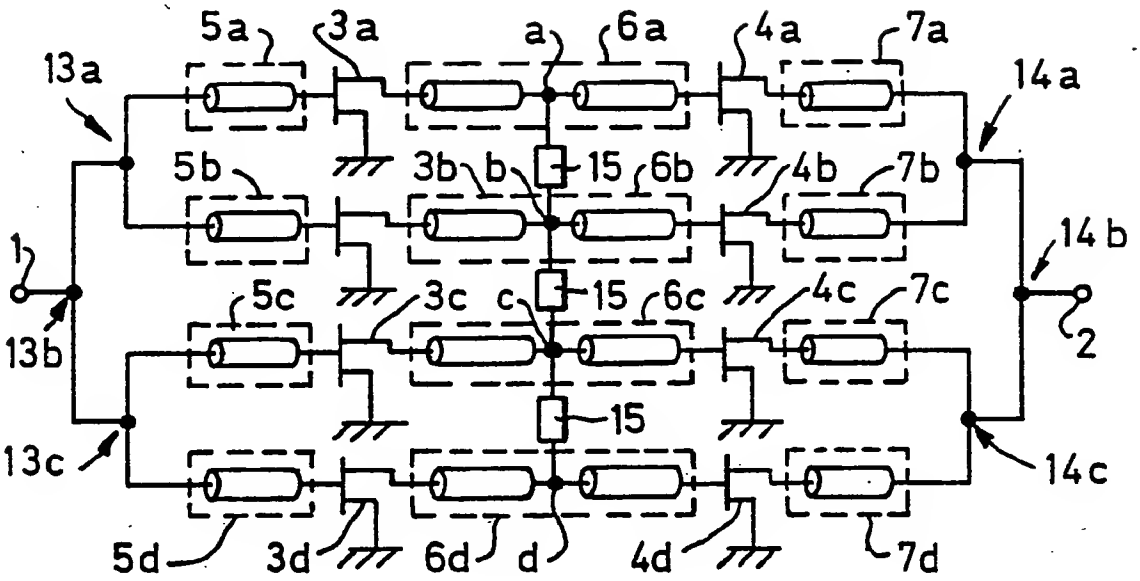

FIG.4.

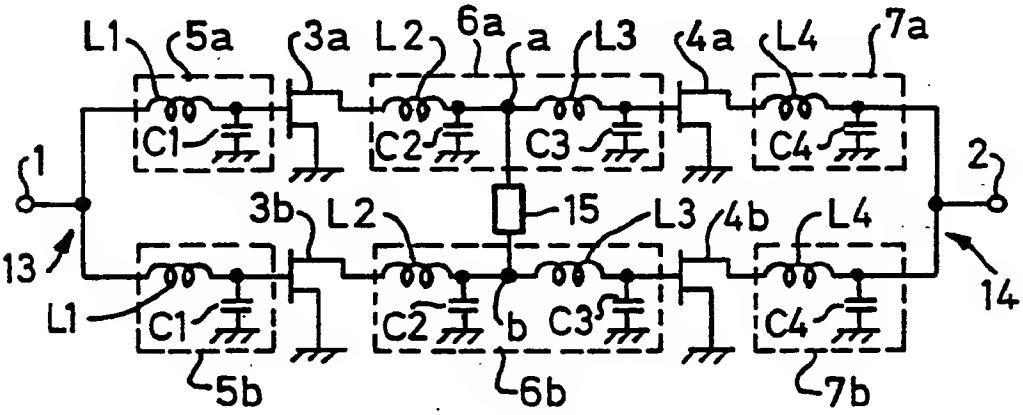

FIG.5.

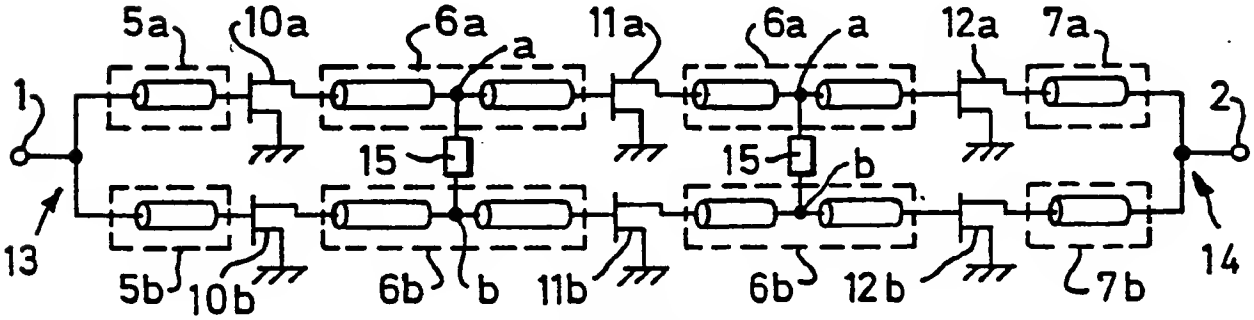

FIG.6.

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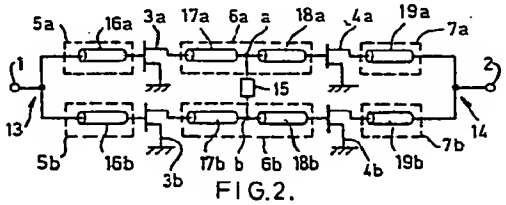

FIG.2.

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 88 30 3080

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	MICROWAVE JOURNAL, vol. 25, no. 3, March 1982, pages 51,52,54,56,58,60,62,64,66, Dedham, Mass., US; J.M. SCHELLENBERG et al.: "A new approach to FET power amplifiers" * Page 51, column 2, lines 31-35; page 52, column 2, line 19 - page 54, column 1, line 18; page 54, column 1, lines 57-61; page 54, column 2, lines 18-28; figure 3 *	1,2	H 03 F 3/60
A	IDEM	4	
Y	DE-A-3 324 540 (SIEMENS AG) * Page 4, lines 1-17; page 2, lines 19-30; claims 1,3; figure 2 *	1,2	
A		4	
A	US-A-3 963 993 (G.R. HOFFMAN et al.) * Column 1, lines 37-42; column 2, lines 15-34; column 3, lines 25-52; claims 1,2,10; figure 1 *	1,2,4	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	IEEE INTERNATIONAL ELECTRON DEVICE MEETING 1979, TECHNICAL DIGEST, Washington, DC, 3rd-5th December 1979, pages 266-268, IEEE, New York, US; "A monolithic GaAs X-band power amplifier" * Page 266, column 1, lines 20-26; page 266, column 2, lines 28-30; page 267, column 1, lines 32-52; figures 4,7 *	1,5	H 03 F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	07-04-1989	BUTLER N.A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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